Chapter 16
Star Birth

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## Star-Forming Clouds

- Stars form in dark clouds of dusty gas in interstellar space
- The gas between the stars is called the **interstellar medium**

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**Best infrared images of newborn stars and surrounding clouds from the NASA Spitzer Telescope**

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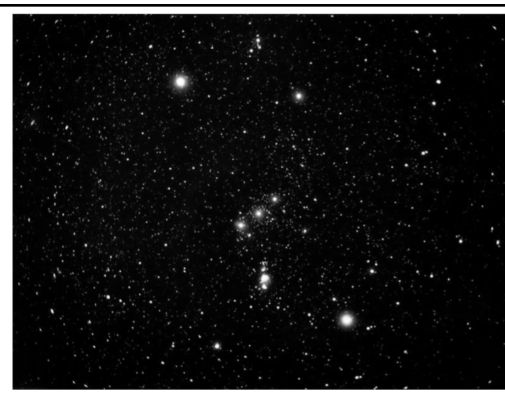

**Star formation in the Orion Nebula**

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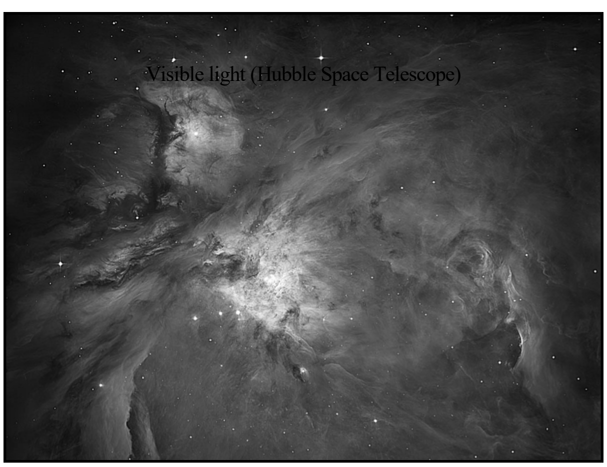


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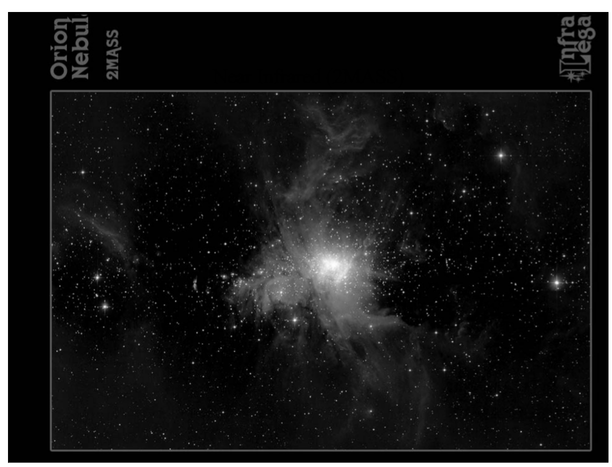


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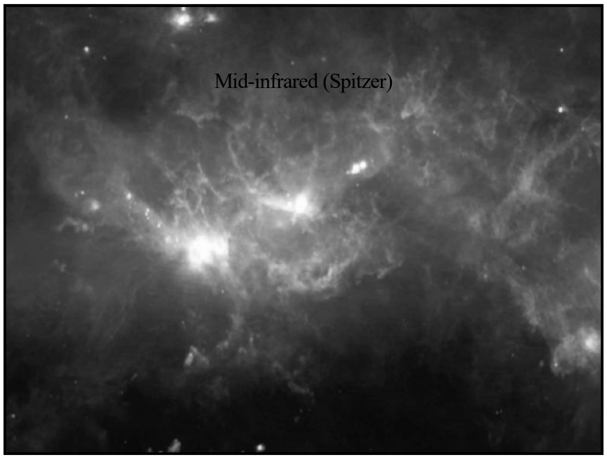


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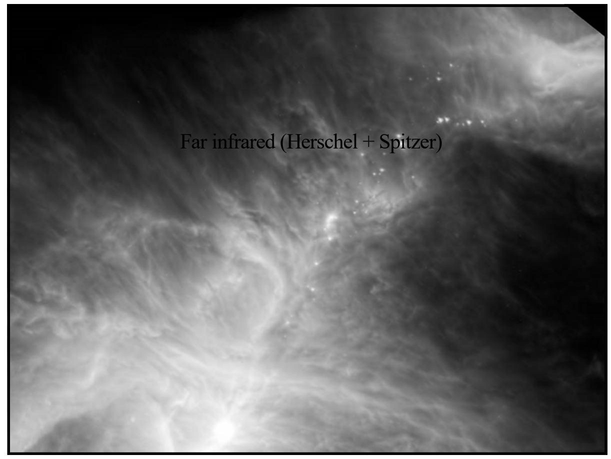


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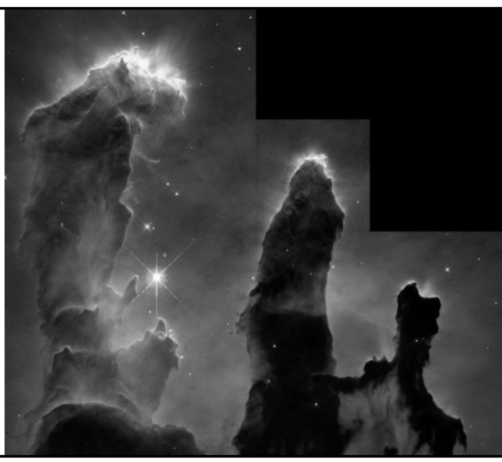

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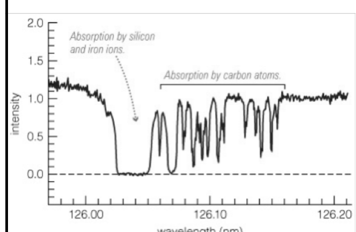
## Composition of Clouds




- Use absorption lines in the spectra of stars
- 70% H, 28% He, 2% heavier elements
- Atomic H gas (radio, low density)
- Molecular gas (radio, high density)
- Dust

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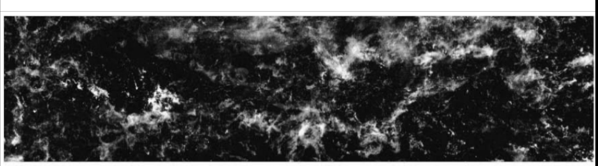
## Molecular Clouds



- Most of the matter in star-forming clouds is in the form of molecules ($H_2$ and CO = carbon monoxide)
- Temperature of 10-30 K and a density of about 300 molecules per cubic cm

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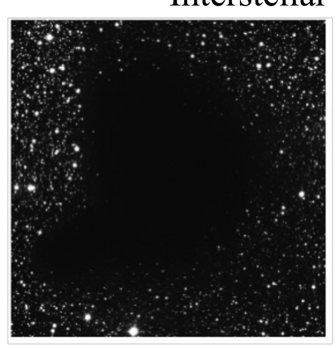
## Interstellar Dust



- Tiny particles of *interstellar dust* block our view
- < 1 micrometer, made of C, O, Si, Fe
- About 1% of mass
- Causes background stars to appear fainter and redder

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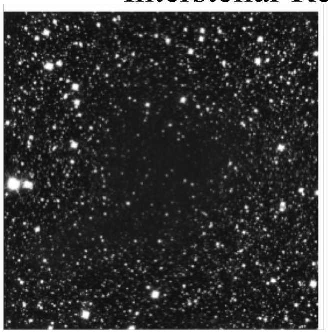
## Interstellar Reddening



- Long-wavelength infrared light passes through a cloud more easily than visible light

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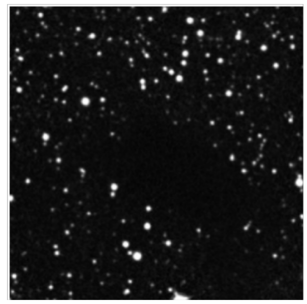
## Observing Newborn Stars



- Visible light from a newborn star is often blocked by dusty clouds where the star formed

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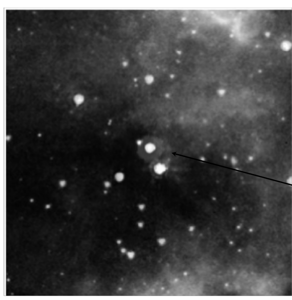
## Observing Newborn Stars



- Observing the infrared light from a cloud can reveal the newborn star embedded inside it

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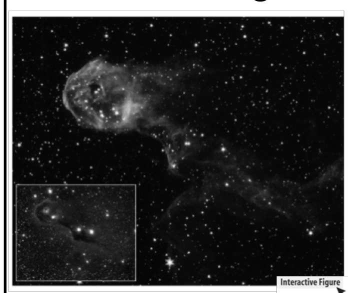
## Glowing Dust Grains




- Dust grains that absorb visible light heat up and emit infrared light

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## Gravity versus Pressure

- Gravity can create stars only if it can overcome the force of thermal pressure in a cloud (plus turbulence and magnetic fields)
- But contraction leads to heating (pressure)
- Emission lines from molecules in a cloud can prevent a pressure buildup by converting thermal energy into infrared and radio photons

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**Gravity wins over pressure when the mass of a cloud exceeds the Jeans Mass:**

**$18\,(T^{3}/n)^{1/2}$ solar masses**
**($n$ = no. atoms per cubic cm)**

**Dark nebula $T$=10, $n$=$10^5$   Jeans Mass=1.8**

**Jeans Mass drops as $n$ increases:**
**can form lower mass clumps (stars) as cloud collapses - *fragmentation***

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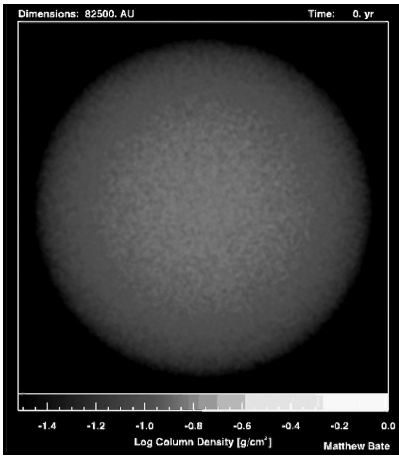


## Cloud Fragmentation

- Each lump of the cloud in which gravity can overcome pressure can go on to become a star
- A large cloud can make a whole cluster of stars

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## *Thought Question*

What would happen to a contracting cloud fragment if it were not able to radiate away its thermal energy?

A. It would continue contracting, but its temperature would not change
B. Its mass would increase
C. Its internal pressure would increase

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## Star Birth: Trapping of Thermal Energy

- As contraction packs the molecules and dust particles of a cloud fragment closer together, it becomes harder for infrared and radio photons to escape
- Thermal energy then begins to build up inside, increasing the internal pressure
- Contraction slows down, and the center of the cloud fragment becomes a **protostar**

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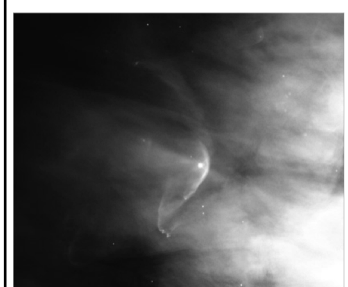
## Growth of a Protostar



- Matter from the cloud continues to fall onto the protostar until either the protostar or a neighboring star blows the surrounding gas away

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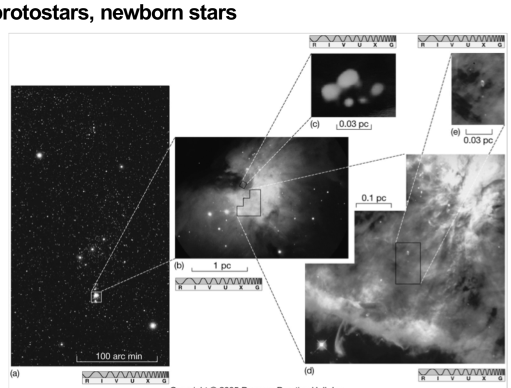
**Orion Nebula: cloud fragments, protostars, newborn stars**



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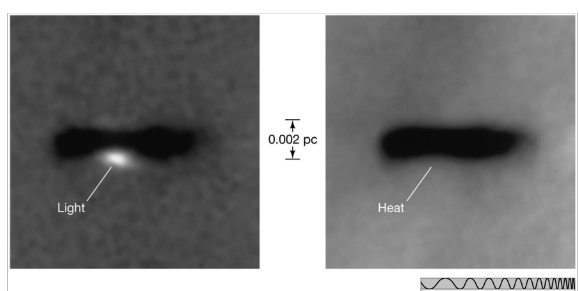
**Protostars with disks in the Orion nebula.**

**Disks are probable birthplace of planets.**



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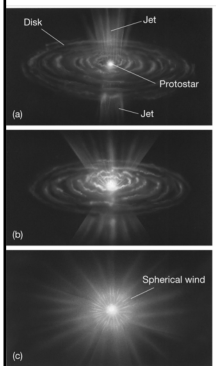
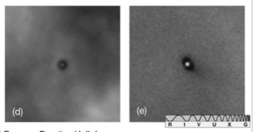



**Angular momentum of cloud leads to *disks* and *jets*. Protostars have strong winds, which clear out an area around the star roughly the size of our solar system.**



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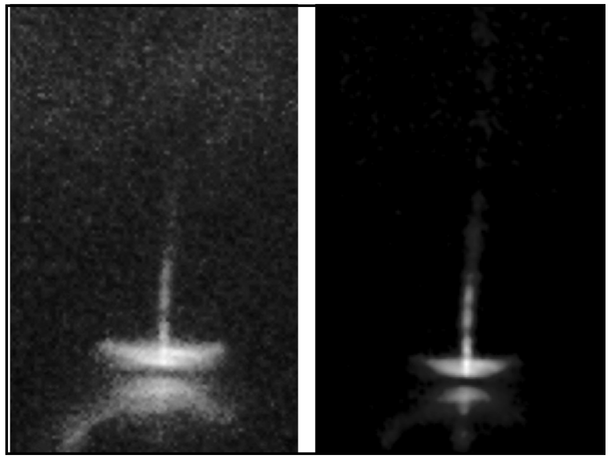

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## From Protostar to Main Sequence

- Protostar looks starlike after the surrounding gas is blown away, but its thermal energy comes from gravitational contraction, not fusion
- Contraction must continue until the core becomes hot enough for nuclear fusion
- Contraction stops when the energy released by core fusion balances energy radiated from the surface—the star is now a *main-sequence star*

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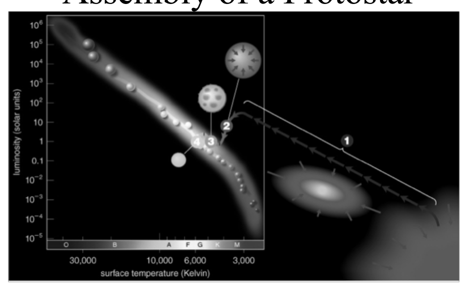
## Assembly of a Protostar




- Luminosity and temperature grow as matter collects into a protostar

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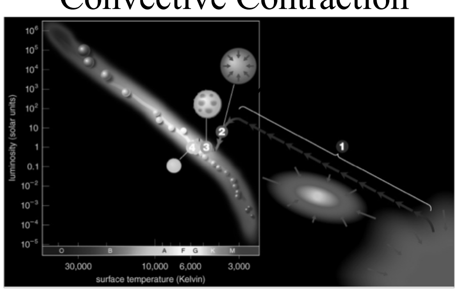
## Convective Contraction




- Surface temperature near 3,000 K; energy transport by convection

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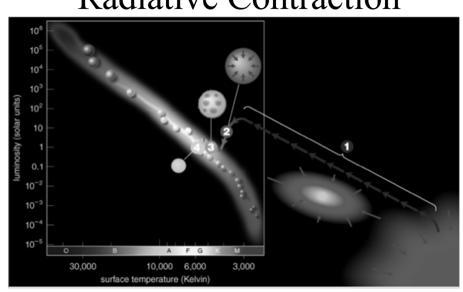
## Radiative Contraction




- Luminosity nearly constant while radiation transports energy out

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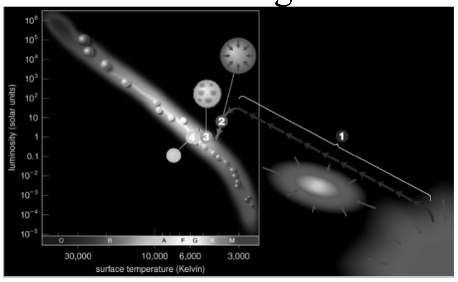
## Self-Sustaining Fusion




- Core temperature continues to rise until star arrives on the main sequence

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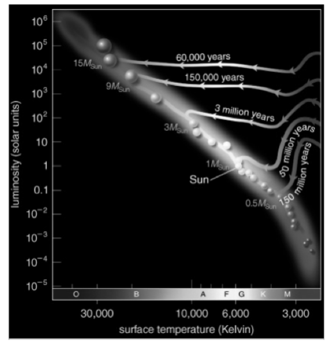
## Life Tracks for Different Masses




- Models show that Sun required about 30 million years to go from protostar to main sequence
- Higher-mass stars form faster
- Lower-mass stars form more slowly

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## Smallest Stars: Fusion and Contraction

- Fusion will not begin in a contracting cloud if some sort of force stops contraction before the core temperature rises above $10^7$ K.
- Thermal pressure cannot stop contraction because the star is constantly losing thermal energy from its surface through radiation
- **Degeneracy Pressure:** Laws of quantum mechanics prohibit two **electrons** from occupying same state in same place

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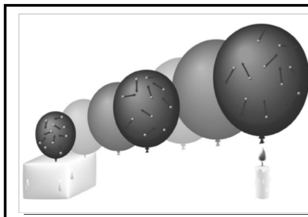
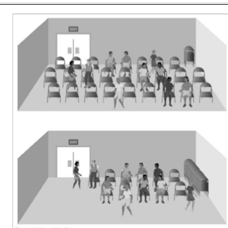


**Thermal Pressure:**

Depends on heat content

The main form of pressure in most stars



**Degeneracy Pressure:**

Particles can't be in same state in same place

Doesn't depend on heat content

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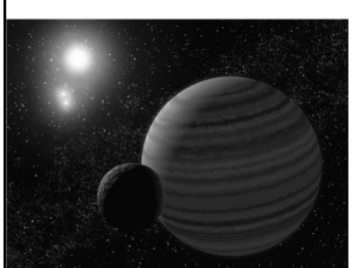
## Brown Dwarfs



- Degeneracy pressure halts the contraction of objects with $<0.08 M_{Sun}$ before core temperature become hot enough for fusion
- Starlike objects not massive enough to start fusion are **brown dwarfs**

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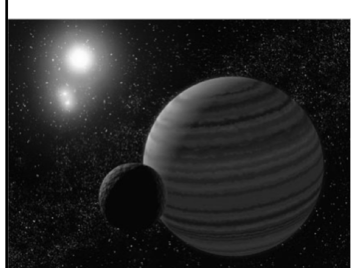
## Brown Dwarfs



- A brown dwarf emits infrared light because of heat left over from contraction (L, T, and Y spectral classes)
- Its luminosity gradually declines with time as it loses thermal energy

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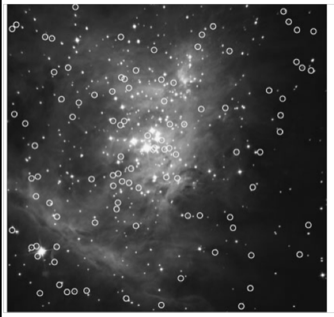
## Brown Dwarfs in Orion



- Infrared observations can reveal recently formed brown dwarfs because they are still relatively warm and luminous

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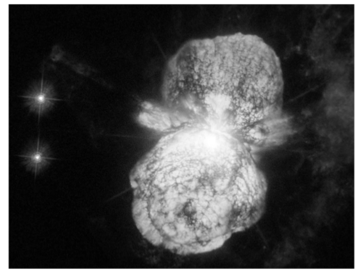
## Largest Stars: Radiation Pressure



- Photons exert a slight amount of pressure when they strike matter
- Very massive stars are so luminous that the collective pressure of photons drives their matter into space

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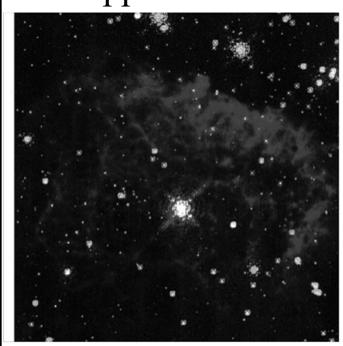
## Upper Limit on a Star's Mass



- Models of stars suggest that radiation pressure limits how massive a star can be without blowing itself apart
- Observations have not found stars more massive than about $150M_{Sun}$ (Pistol Star)

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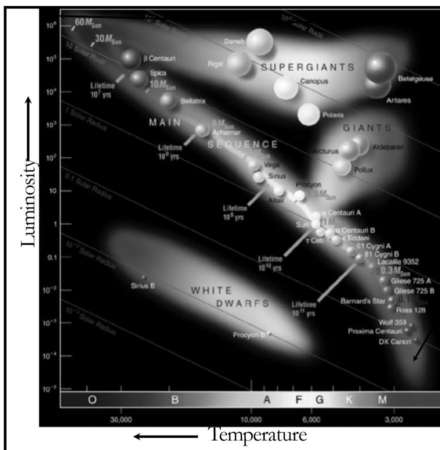


Stars more massive than $150M_{Sun}$ would blow apart

Stars less massive than $0.08M_{Sun}$ can't sustain fusion

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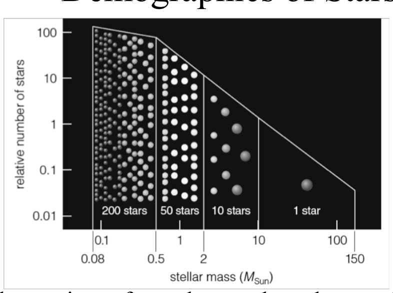
## Demographics of Stars




- Observations of star clusters show that star formation makes many more low-mass stars than high-mass stars

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